# Economic Impacts of Climate Change on California Agriculture

!! RESULTS PRELIMINARY !!

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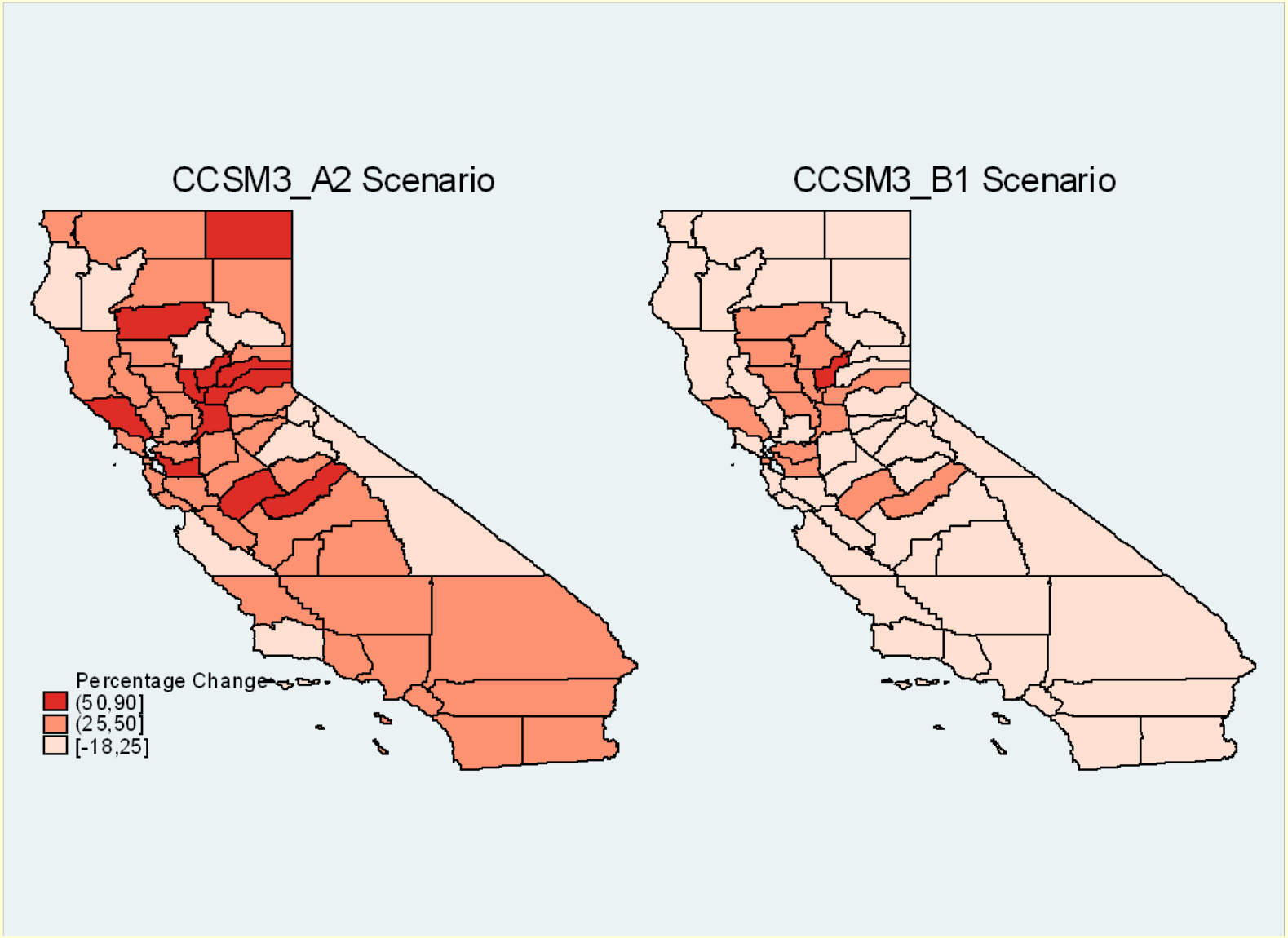
# Project Goals

- Assess impacts on California Agriculture of a specific change in the climate
- Approach
  - Estimate how weather and climate affect profits in California agriculture
  - Use two forecasts of temperature and precipitation changes anticipated this century
  - Simulate the effects of two climate forecasts on profits in California agriculture
  - Examine overall as well as for specific crops

# Scenarios (from IPCC/SRES)

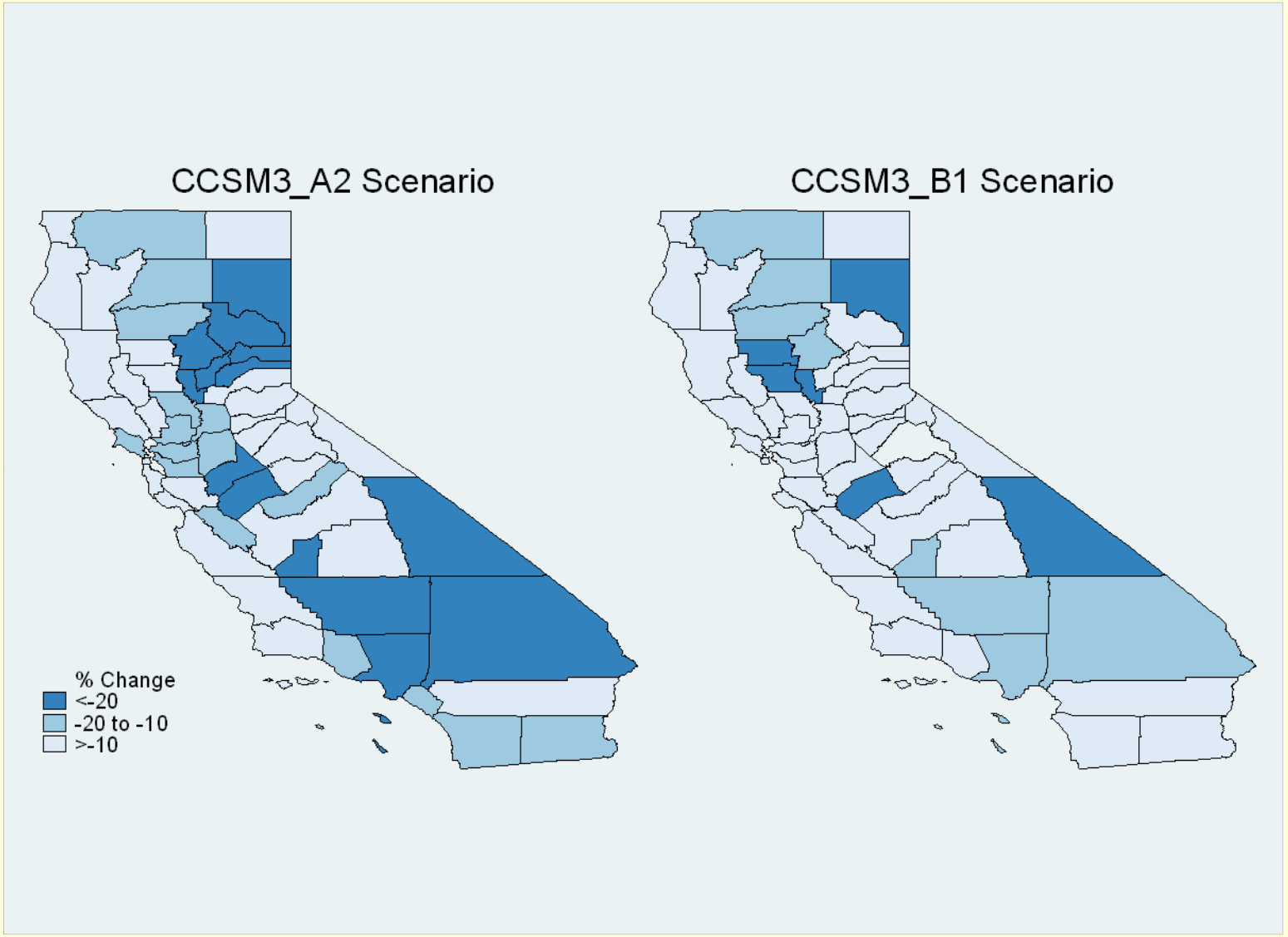
- Downscaled to county
- A2 – business as usual
- B1 – more moderate change in climate

# Predicted Change, Annual Degree-Days
## (% Change in 2070-99 relative to 1950-2005)



# Predicted Change, Annual Precipitation

## (% Change in 2070-99 relative to 1950-2005)



# Methodology

Model 1: Effect of weather on ag profits:

$$(1) \quad y_{ct} = \alpha_c + \lambda_t + X_{ct}\theta + \sum_{k=1}^{K} \beta_k W_{kct} + \varepsilon_{ct}$$

c – county
t -- year
y – profits (revenue less costs)
α – county fixed effect
λ – year effect
X – non-climate land characteristics
W – weather
k – index on types of weather statistics

To estimate:
α, λ, θ, β

# Methodology--cont

Model 2: Effect of weather and climate on ag profits:

$$(2)\quad y_{ct} = \alpha_c + \lambda_t + X_{ct}\theta + \sum_{k=1}^{K} \beta_k W_{kct} + \sum_{k=1}^{K} \delta_k C_{kct} + \varepsilon_{ct}$$

c – county
t -- year
y – profits (revenue less costs)
α – county fixed effect
λ – year effect
X – non-climate land characteristics
W – weather
C – expected climate (30 year average)
k – index on types of weather statistics

To estimate:
α, λ, θ, β, δ

# Total Impacts

$$(3)\quad IMPACT_c = ACRES_c \times \left( \sum_k \hat{\beta}_k \Delta W_{kc} + \sum_k \hat{\delta}_k \Delta C_{kc} \right)$$

# Data—all at county level

- Farm revenues, expenditures and profits
  - Census of Ag – 1987, 1992, 1997, 2002
- Crop Production and yields
  - County Agricultural Commissioners Data
- Soil Quality Data
  - National Resource Inventory (NRI)
- Historical Weather Data
  - National Climatic Data Center

# Summary Stats

| | 1987 | 1992 | 1997 | 2002 |
|---|---|---|---|---|
| **Aggregate state totals** | | | | |
| Acres of Farmland (Mil.) | 30.60 | 28.98 | 27.70 | 27.58 |
| Total Sales ($Mil.) | 21,996.0 | 22,884.7 | 28,037.5 | 28,794.9 |
| Production Expenditures ($Mil.) | 17,387.9 | 18,628.7 | 20,545.8 | 22,965.9 |
| Total Profit ($Mil.) | 4,608.1 | 4,255.9 | 7,491.8 | 5,829.0 |
| **County averages** | | | | |
| Sales ($Mil.) | 372.8 | 387.9 | 475.2 | 496.5 |
| Production Expenditures ($Mil.) | 294.7 | 315.7 | 348.2 | 396.0 |
| Profits ($Mil.) | 78.1 | 72.1 | 127.0 | 100.5 |
| Profits Per Acre (1$/acre) | 150.6 | 146.9 | 270.5 | 211.4 |

# Specific Crops

| | County Averages: | | | | |
|---|---|---|---|---|---|
| **Crop** | **Counties** | **Yield** | **Total value ($ Mil.)** | **Dollar per acre** | **State total value ($ Mil.)** |
| Almonds | 18.8 | 0.59 | 61.1 | 2,057.4 | 1,148.8 |
| Avocados | 11.0 | 2.80 | 30.1 | 4,707.2 | 332.2 |
| Broccoli | 12.6 | 5.93 | 37.4 | 3,941.8 | 470.2 |
| Cotton | 9.4 | 5.51 | 177.4 | 1,366.0 | 1,657.6 |
| Grapes (non-wine) | 14.7 | 6.62 | 110.1 | 4,787.7 | 1,618.0 |
| Hay | 51.4 | 4.34 | 23.0 | 534.0 | 1,179.4 |
| Lemons | 11.5 | 13.44 | 32.2 | 6,819.1 | 383.3 |
| Lettuce | 15.4 | 13.80 | 82.9 | 5,534.9 | 1,278.0 |
| Oranges | 12.8 | 10.90 | 81.2 | 4,779.6 | 1,039.9 |
| Pistachios | 9.6 | 0.87 | 22.3 | 3,059.8 | 213.6 |
| Rice | 15.7 | 3.12 | 35.1 | 994.3 | 552.4 |
| Strawberries | 14.3 | 22.34 | 52.9 | 27,070.2 | 752.2 |
| Tomatoes | 22.0 | 24.00 | 42.8 | 5,583.7 | 942.5 |
| Walnuts | 32.7 | 1.09 | 12.4 | 1,636.8 | 405.6 |
| Wine Grapes | 30.1 | 5.11 | 49.6 | 3,457.6 | 1,489.7 |
| **Total** | --- | --- | --- | --- | 13,463.4 |

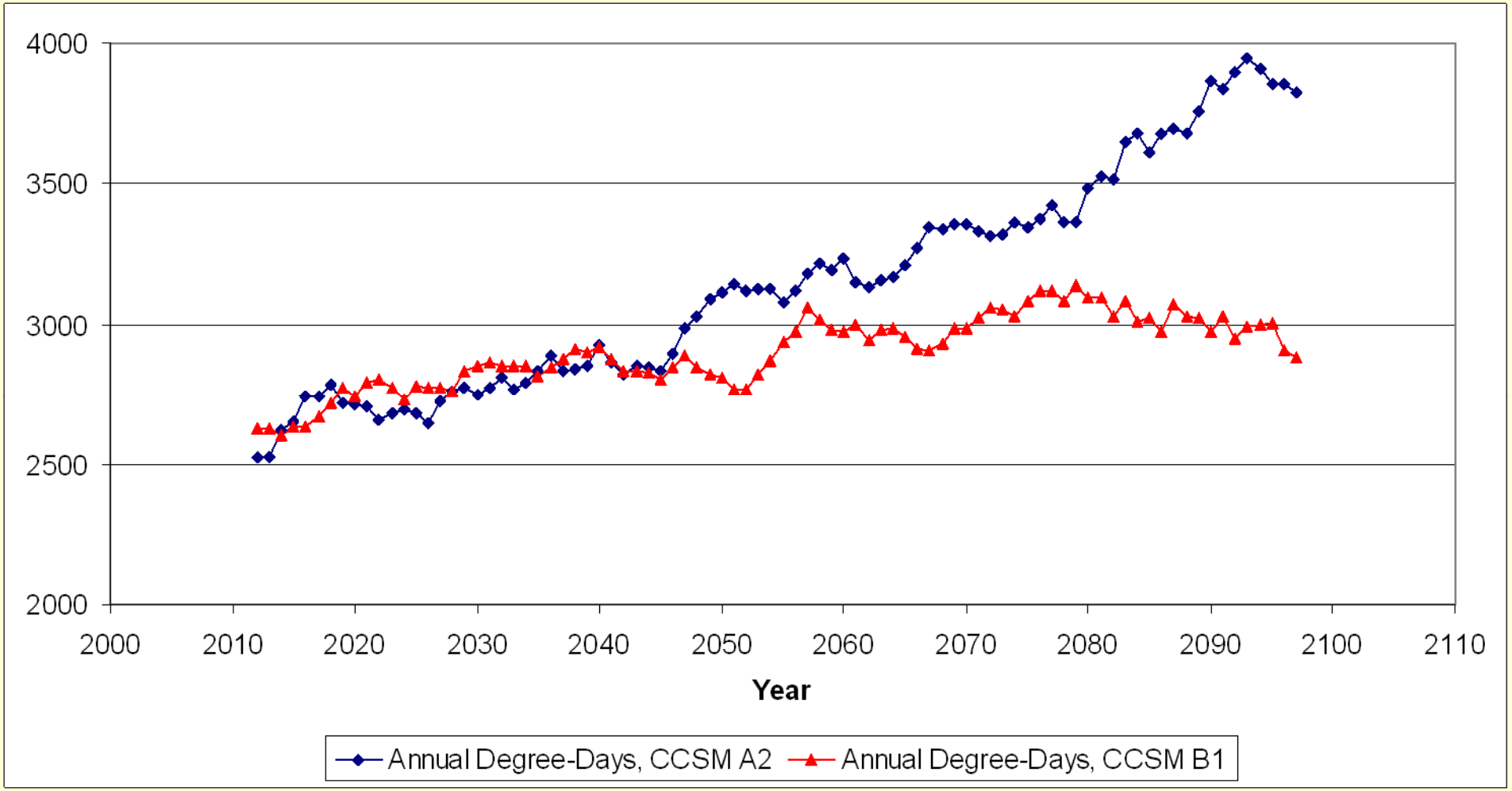
# Weather and Climate

- Degree-days
  - 8$^{o}$C base
  - 32$^{o}$C ceiling
- Precipitation
- Climate Expectations:  Average weather over previous 30 years

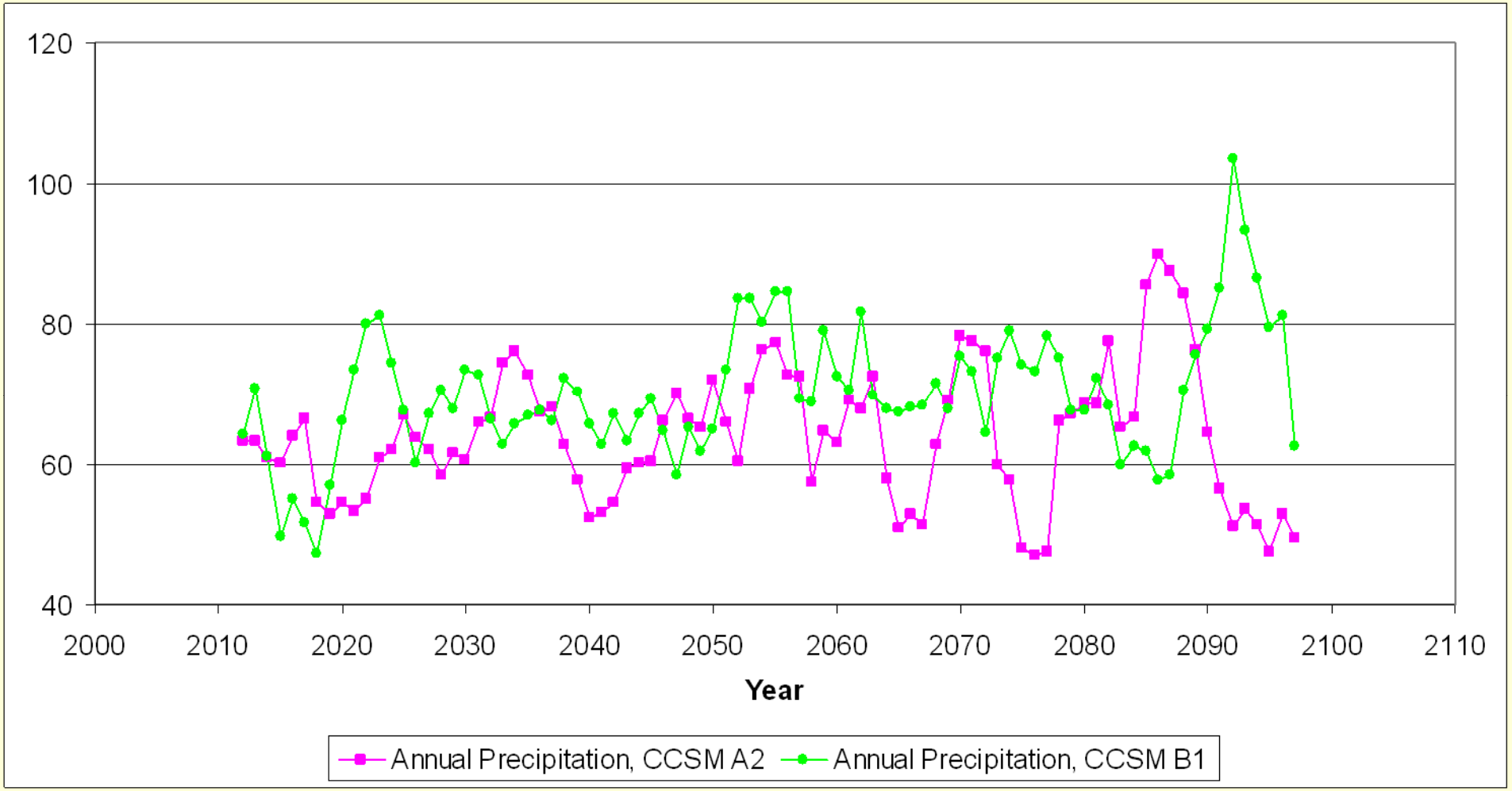
# Country Level Summary Stats
# Average Weather Realizations

| | Actual | Projected: CCSM-B1 (Levels) | | | Projected: CCSM-A2 (Levels) | | |
|---|---|---|---|---|---|---|---|
| | 1950-2005 | 2010-2039 | 2040-2069 | 2070-2099 | 2010-2039 | 2040-2069 | 2070-2099 |
| **All Year** | | | | | | | |
| Degree-Days (8-32) | 2,601.5 | 2,765.8 | 2,897.6 | 3,016.6 | 2,714.5 | 3,096.6 | 3,612.3 |
| Total Precipitation (cm) | 71.0 | 66.0 | 71.5 | 72.6 | 63.6 | 62.8 | 64.9 |
| **Winter** | | | | | | | |
| Degree-Days | 204.6 | 224.4 | 251.1 | 266.2 | 215.6 | 280.5 | 384.7 |
| Total Precipitation | 35.5 | 34.6 | 35.6 | 35.7 | 31.3 | 32.4 | 32.3 |
| **Spring** | | | | | | | |
| Degree-Days | 762.1 | 813.8 | 846.4 | 865.2 | 788.2 | 888.8 | 1,049.3 |
| Total Precipitation | 8.6 | 8.9 | 8.1 | 9.4 | 8.5 | 7.8 | 7.6 |
| **Summer** | | | | | | | |
| Degree-Days | 1,234.4 | 1,313.3 | 1,358.2 | 1,401.9 | 1,318.9 | 1,416.8 | 1,584.6 |
| Total Precipitation | 2.0 | 1.5 | 1.8 | 1.5 | 1.7 | 1.3 | 1.0 |
| **Fall** | | | | | | | |
| Degree-Days | 400.4 | 414.3 | 441.9 | 483.4 | 391.8 | 510.5 | 593.6 |
| Total Precipitation | 25.0 | 21.0 | 26.0 | 26.1 | 22.1 | 21.3 | 24.0 |
| Observations | 3248 | 1740 | 1740 | 1740 | 1740 | 1740 | 1740 |

# Degree-Days: A2 and B1 Scenarios



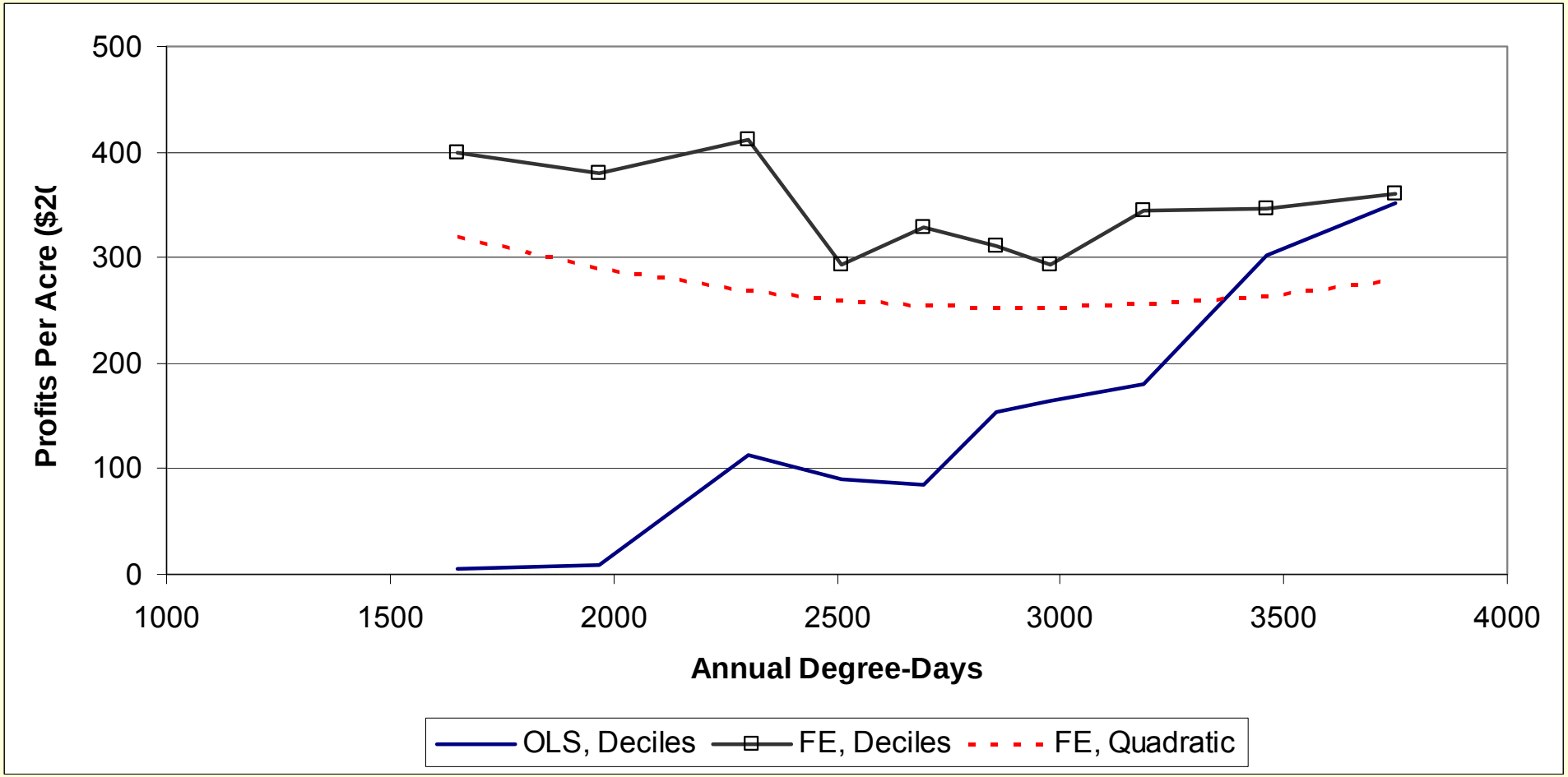
# Precipitation: A2 and B1 Scenarios



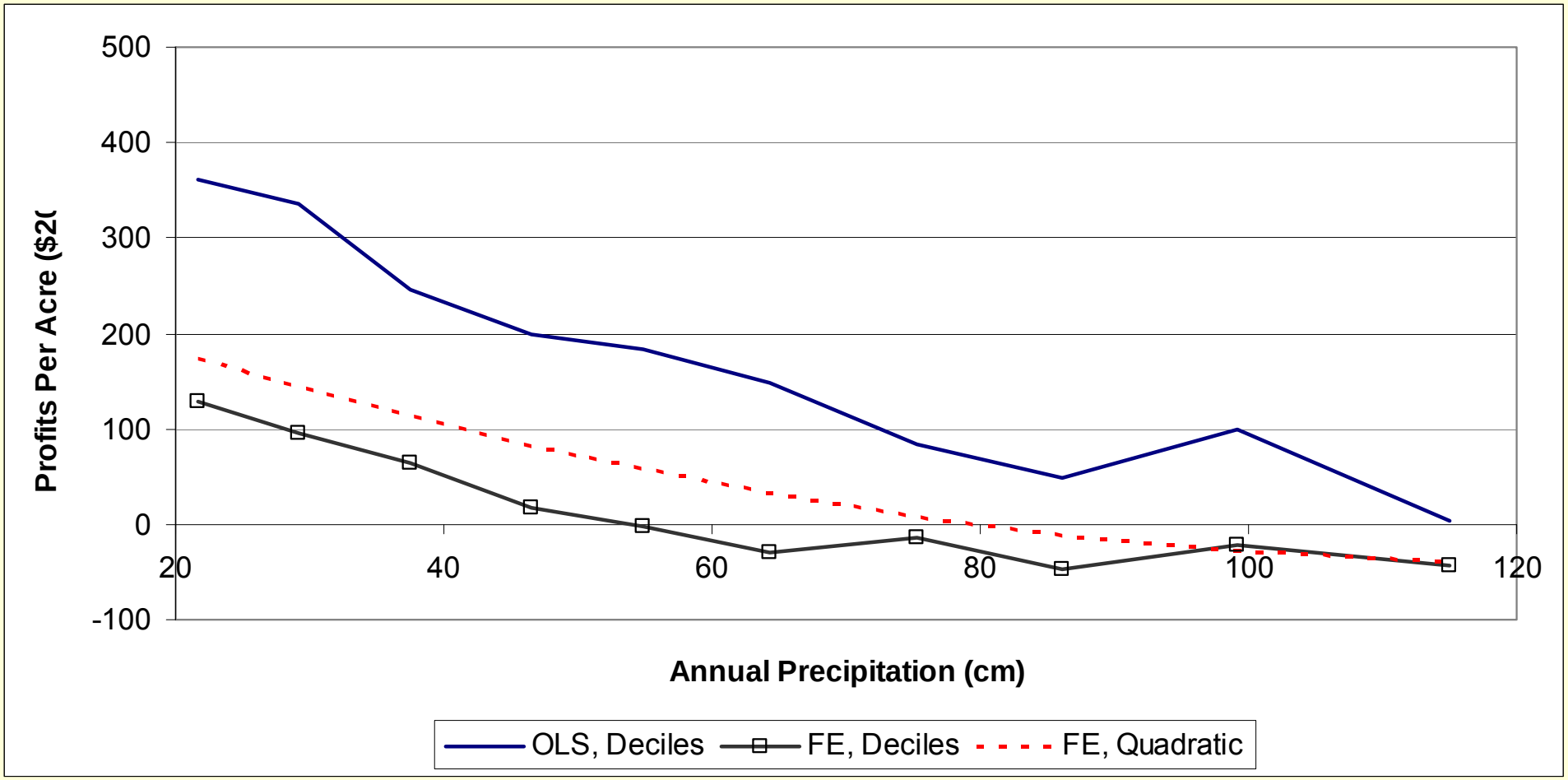
# Estimation—annual weather & climate

| | | Equation (1) -- weather only | | | | | Equation (2) -- weather and climate | | |
|---|---|---|---|---|---|---|---|---|---|
| Models | | (1) | (2) | (3) | (4) | | (5) | (6) | |
| Weather Variables | | | | | | | | | |
| | Degree Days | 0.1100 | 0.1000 | -0.0100 | -0.2500 | | 0.0630 | 0.1809 | |
| | | 0.0280 | 0.0790 | 0.0530 | 0.3229 | | 0.0360 | 0.2327 | |
| | | | | | | | | | |
| | Degrees Days Squared | --- | 0.0001 | --- | 0.0392 | | --- | -0.0210 | |
| | (x1000) | | 0.0157 | | 0.0527 | | | 0.0400 | |
| | | | | | | | | | |
| | Precipitation | -2.6000 | -6.2190 | -2.7900 | -5.4160 | | -2.1700 | 4.7170 | |
| | | 0.7100 | 2.0420 | 1.2400 | 2.7179 | | 1.2300 | 2.1400 | |
| | | | | | | | | | |
| | Precipitation Squared | --- | 0.0250 | --- | 0.0230 | | --- | 0.0234 | |
| | | | 0.0135 | | 0.0168 | | | 0.0130 | |
| | | | | | | | | | |
| Climate Variables | | | | | | | | | |
| | Degree Days | --- | --- | --- | --- | | 0.0566 | -0.0510 | |
| | | | | | | | 0.0370 | 0.2685 | |
| | | | | | | | | | |
| | Degrees Days Squared | --- | --- | --- | --- | | --- | 0.0180 | |
| | (x1000) | | | | | | | 0.0466 | |
| | | | | | | | | | |
| | Precipitation | --- | --- | --- | --- | | -0.5100 | -3.9700 | |
| | | | | | | | 1.1020 | 3.7570 | |
| | | | | | | | | | |
| | Precipitation Squared | --- | --- | --- | --- | | --- | 0.0161 | |
| | | | | | | | | 0.0199 | |
| R-squared | | 0.458 | 0.466 | 0.866 | 0.867 | | 0.463 | 0.476 | |
| | | | | | | | | | |
| Controls | | Linear | Quadratic | Linear | Quadratic | | Linear | Quadratic | |
| County Fixed Effects | | No | No | Yes | Yes | | No | No | |
| Year Effects | | Yes | Yes | Yes | Yes | | Yes | Yes | |
| Soil Characteristics | | Yes | Yes | Yes | Yes | | Yes | Yes | |
| # explanatory variables | | 13 | 15 | 71 | 73 | | 16 | 20 | |
| Observations | | 232 | 232 | 232 | 232 | | 232 | 232 | |

# Annual Degree-Days vs. Profit/Acre (Weather only)



# Annual Precipitation vs. Profit/Acre (Weather only)



# Predicted Impacts: A2

(Model 2—weather and climate)

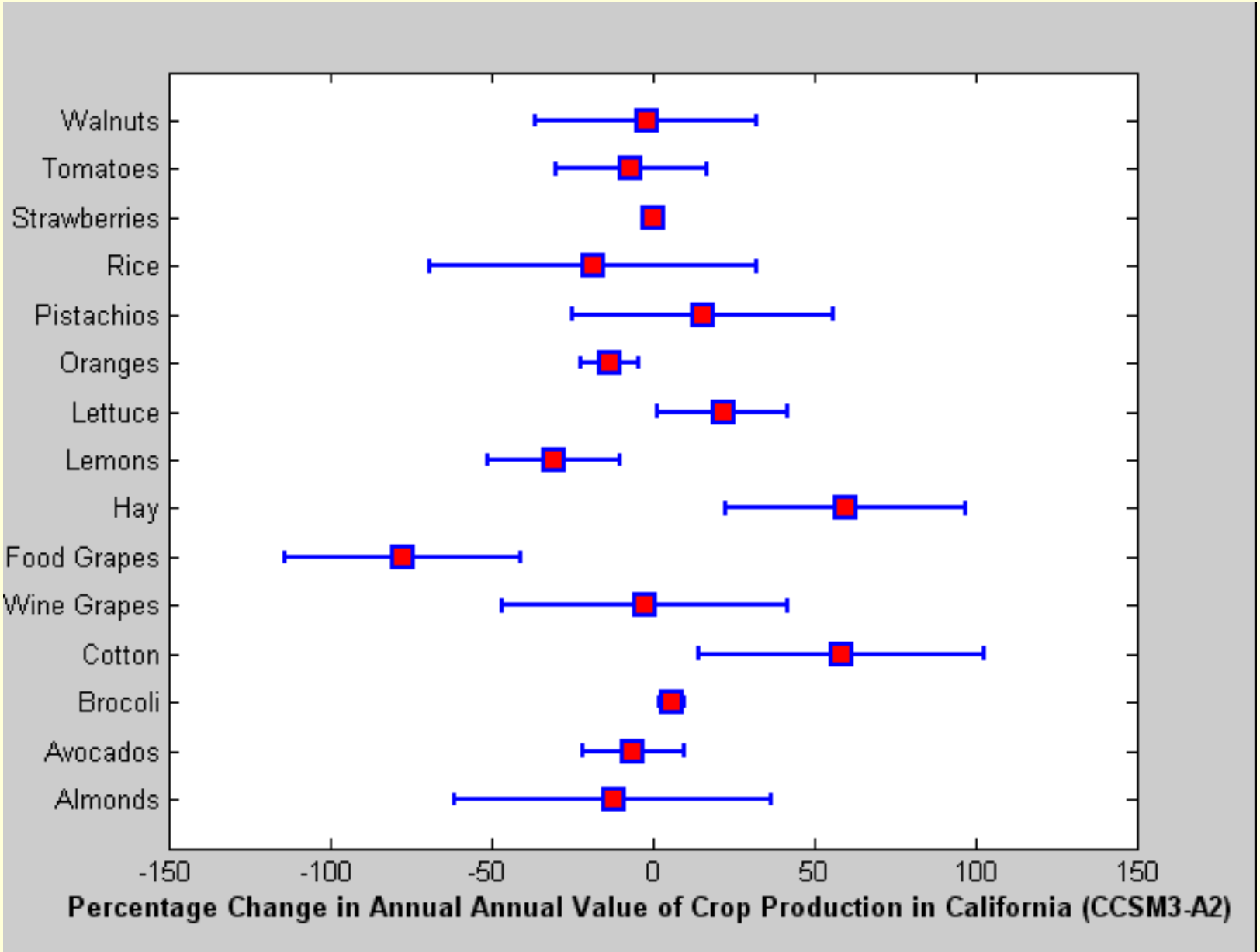
| | Projected Impact: 2040-2069 | | Projected Impact: 2070-2099 | |
|---|---|---|---|---|
| | (1) | (2) | (1) | (2) |
| **Impact on Profits ($2005 Mil.)** | **2,265.9** | **2,331.5** | **3,930.8** | **3,718.3** |
| | **(374.5)** | **(504.1)** | **(839.2)** | **(1270.8)** |
| ***Percent effect*** | *40.9* | *42.0* | *70.9* | *67.0* |
| Due to temperature change | 1,726.2 | 1,503.5 | 3,532.7 | 3,048.5 |
| | (438.1) | (619.2) | (896.6) | (1381.2) |
| Annual temperature effect | 914.4 | 492.5 | 1,871.3 | 836.5 |
| | (522.2) | (802.2) | (1068.6) | (1896.6) |
| Climate effect | 811.8 | 1,010.9 | 1,661.4 | 2,212.0 |
| | (544.6) | (853.1) | (1114.4) | (2043.8) |
| Due to precipitation change | 539.7 | 828.1 | 398.2 | 669.8 |
| | (146.6) | (238.2) | (108.1) | (199.4) |
| Annual precipitation effect | 437.1 | 404.2 | 322.4 | 333.1 |
| | (246.7) | (261.5) | (182.0) | (197.0) |
| Climate effect | 102.7 | 423.9 | 75.7 | 336.7 |
| | (221.1) | (343.3) | (163.1) | (276.3) |
| Controls | Linear | Quadratic | Linear | Quadratic |
| County fixed-effects | No | No | No | No |
| Year effects | Yes | Yes | Yes | Yes |
| Soil characteristics | Yes | Yes | Yes | Yes |
| Number of explanatory variables | 16 | 20 | 16 | 20 |
| Observations | 232 | 232 | 232 | 232 |

# Predicted Impacts: B1

(Model 2—weather and climate)

| | Projected Impact: 2040-2069 | | Projected Impact: 2070-2099 | |
|---|---|---|---|---|
| | (1) | (2) | (1) | (2) |
| **Impact on Profits ($2005 Mil.)** | **1,109.9** | **1,064.1** | **1,468.9** | **1,382.5** |
| | **(252.8)** | **(358.1)** | **(366.2)** | **(505.5)** |
| ***Percent effect*** | *20.0* | *19.2* | *26.5* | *24.9* |
| Due to temperature change | 1,038.0 | 901.3 | 1,452.6 | 1,265.0 |
| | (263.4) | (383.2) | (368.7) | (521.7) |
| Annual temperature effect | 549.8 | 279.5 | 769.5 | 413.5 |
| | (314.0) | (506.4) | (439.4) | (676.5) |
| Climate effect | 488.2 | 621.8 | 683.2 | 851.5 |
| | (327.4) | (541.1) | (458.3) | (719.6) |
| Due to precipitation change | 71.9 | 162.8 | 16.3 | 117.5 |
| | (19.5) | (54.9) | (4.4) | (53.1) |
| Annual precipitation effect | 58.2 | 85.0 | 13.2 | 67.0 |
| | (32.9) | (41.4) | (7.4) | (32.7) |
| Climate effect | 13.7 | 77.9 | 3.1 | 50.5 |
| | (29.4) | (67.9) | (6.7) | (54.8) |
| Controls | Linear | Quadratic | Linear | Quadratic |
| County fixed-effects | No | No | No | No |
| Year effects | Yes | Yes | Yes | Yes |
| Soil characteristics | Yes | Yes | Yes | Yes |
| Number of explanatory variables | 16 | 20 | 16 | 20 |
| Observations | 232 | 232 | 232 | 232 |

# Crop-Specific Profit Changes



# Conclusions

- Climate change may result in increased total ag profits in state
  - Caveats:  holds prices and water availability constant
- Profits for some crops may rise or fall dramatically
  - Profits from table grapes for instance negatively impacted
- Continuing work
  - Seasonal weather model
  - Expand Dataset
  - Refine functional form